Chapter 6 Method

Previously, a number of navigation aids were implemented and tested as to their effect on subjects' ability to perform wayfinding tasks in virtual worlds (Darken & Sibert, 1993). Although the earlier study addressed the fundamental issues of wayfinding, it did not culminate in a set of generalizable conclusions founded on scientific research. Rather, it presented a number of alternative cues and tools which were shown to improve subjects' performance. The objective of this body of research is to expand on earlier work by examining what environmental information is necessary for wayfinding tasks and to provide generalizable principles as to how this information can be supplied.

These principles will be the foundation of a methodology for the design of wayfinding augmentations to virtual worlds which will facilitate skilled wayfinding (searching and exploratory) behaviors in novice users. These "wayfinding augmentations" are analogous to Lynch's elements of urban design (See Elements of an Environmental Design on page 65) and Passini's map and sign systems. This research is focused on the first step in the evolution of such a methodology.

Design

The experiment described in this chapter was designed to investigate the causal relationship between real world wayfinding principles and performance on wayfinding tasks in virtual worlds. Stated formally, it is intended to show that

> real-world wayfinding and environmental design principles are effective in designing virtual worlds which support skilled wayfinding behavior.

All relevant terms in this statement have been defined in the previous chapters. Implicitly, there are two parts to this investigation:

1. Does such a causal relationship exist and if so,
2. Describe the effect(s).

The basic form of the experiment is to measure performance on wayfinding tasks of each subject in several virtual world treatments. Some treatments adhere to some or all of the wayfinding principles; others do not. Therefore, the independent variable is adherence to or violation of wayfinding principles. The dependent variable is performance and behavior on specified wayfinding tasks. There were four treatments used in the experiment:

- **The Control Treatment**: No wayfinding assistance provided
- **The Grid Treatment**: Adherence to organizational principles
- **The Map Treatment**: Adherence to map principles
- **The Map/Grid Treatment**: Adherence to both organizational and map principles

Each of these treatments will be described in detail in Stimuli and Apparatus on page 104.

While we cannot have a direct effect on mental (perceptual and cognitive) processes and resources, we can manipulate the stimuli and observe the effect it has on the response. In fact, the effects of changes in the stimuli can be observed both externally in the response behavior (wayfinding task performance) and internally in both the cognitive map and in search strategies, each of which is accessible.

Data collection for exploratory wayfinding tasks was done using map drawing exercises (Lynch, 1960; Howard & Kerst, 1981) to elicit information about the subject's cognitive map for the world used in each treatment. This has been shown to be an effective method of gaining an understanding of a subject's experience with an environment (Lynch, 1960; Passini, 1984). Subject-drawn maps not only show their ability to infer spatial relationships between places in the space but also show what spatial information was used for wayfinding and what spatial information was ignored or not perceived at all.

Data collection for searching wayfinding tasks was done using execution timings, viewpoint position and orientation sampling, and a verbal protocol analysis (Wilson &

Corlett, 1991) with video. As the subject would locate targets within each environment, a timing was taken to allow analysis of the overall time to complete the task and also the time to complete particular subtasks within the treatment. While traversing the world, the position and orientation of the subject's viewpoint within the environment was sampled approximately once per second. This data was used to analyze a variety of variables associated with the tasks. Also, the data points could be viewed superimposed on the world itself to show the path the subject traversed in its entirety. Lastly, all treatments of all subjects were video and audio taped for search strategy analysis. The videotape was taken to show only the view of the subject as seen through the display apparatus with a voice-over verbal protocol. Post-trial analysis could then be done by watching the videotape while transcribing relevant comments made by the subject or actions noted by the experimenter.

All subjects were tested on all treatments. Due to the well-documented gender-based differences in spatial abilities (Ekstrom, French, Harman, & Dermen, 1976; McGee, 1979), five male and five female subjects participated in the study. The total number of subjects was restricted to ten for two reasons: 1) the subject pool is severely limited due to the location of the laboratory and 2) the total time taken to complete all tests and trials per subject was approximately three hours. All subjects had a technical background and were between the ages of 20 and 45. A technical background was desired in order to eliminate all subjects with an anti-technology bias[†] which may affect task performance. Experience with the actual apparatus or similar devices was not required.

A primary concern in the experimental design was with problems associated with carryover between trials within subjects. That is, lessons learned on one treatment can be applied to a subsequent treatment, thus altering perceived behavior. Wilson and Corlett (1991) suggest two alternative solutions to this problem. The trials could be limited in time duration as to minimize the amount of learning that can take place. This was an unaccept-

† Also known as the "computer-illiterate", these subjects tend to hold hostile or negative presuppositions which may adversely affect their ability to comfortably perform the required tasks.

able solution since a certain type of learning was intended to take place; that of spatial knowledge acquisition. Another alternative was to expose all subjects to all the treatments for some constant time duration before testing begins. In the case of this experiment, each subject was exposed to the control treatment (on a separate environment) for a specified time duration before testing began. This minimized the cross-talk between treatments (See Procedure on page 110) yet allowed the subject time to become acclimated with the apparatus and the experimental procedure. Also, the order of presentation for the treatments as well as the worlds to which those treatments were applied was assigned at random.

Stimuli and Apparatus

There were five environments built for the purposes of this experiment. Each of the worlds was one square degree of latitude (or longitude) in size (3600nm^2 or 111120m^2). This is also equivalent to one complete, full resolution DTED (Digital Terrain Elevation Data) cell (See Figure 6-1). However, the worlds used in this experiment were not actual terrain data but were constructed manually using a geometric modeling tool. The worlds are perfect squares containing large areas of open sea with land masses. Each world was designed so that the land masses would not exceed 75 meters in altitude. This was done to eliminate the need for collision detection with the viewpoint during navigation which can be a computationally expensive task. By restricting the terrain to a set maximum altitude and limiting the viewpoint to the same minimum altitude, the problem is effectively eliminated.

The maximum altitude was set at 400 meters. This is a subjectively selected value intended to allow some vertical movement without allowing the subject to gain so much altitude as to be able to look down at the entire environment in a “bird’s eye view.”

The land masses were constructed by hand so as to be topographically distinct from one another. However, no attempt was made to provide any sort of natural landmark which could be used for navigation such as mountains, valleys, or other unusual landforms. The ability of subjects to infer the topographical structure of the worlds was partly at issue in the experiment. Each of the environments is shown in Appendix B.

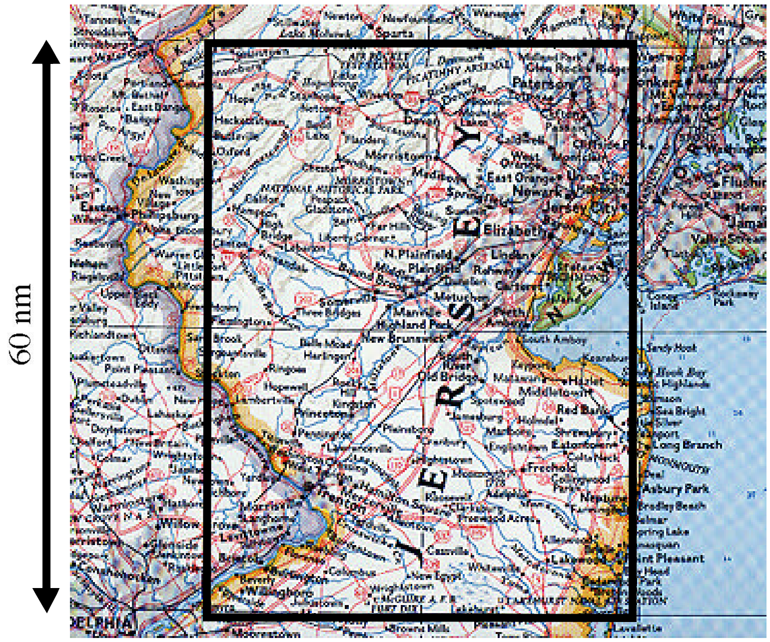

Figure 6-1 One DTED cell could easily cover the region between New York City and Philadelphia.

The worlds were constructed so that a large buffer of open ocean surrounded the land masses on all four sides (See Figure 6-2). This was done to minimize the ability of the navigator to use the “edge” of the world to navigate by. This attempt was not completely successful . Movement was constrained horizontally so that when the subject reached the furthest extent of the world, there would be no distinguishable feature by which to navigate. The subject would be out of view of all land masses. Contact with the virtual edge resulted in an audible “click” cue and motion was immediately stopped at the point of contact. This cue was not provided for collisions with the upper or lower altitude threshold. The original design called for a “wrap around” technique which would map each edge to its opposite edge. This method was rejected in pilot studies when it was determined to be overly disorienting. An important factor in the experimental design was that the task be possible, albeit difficult, in the control treatment.

The land masses are colored by elevation with higher elevations a light green and lower elevations a dark green or brown. The ocean surface is textured with a simple sea texture which has been scaled in an attempt to hide the repetition of its pattern. At higher

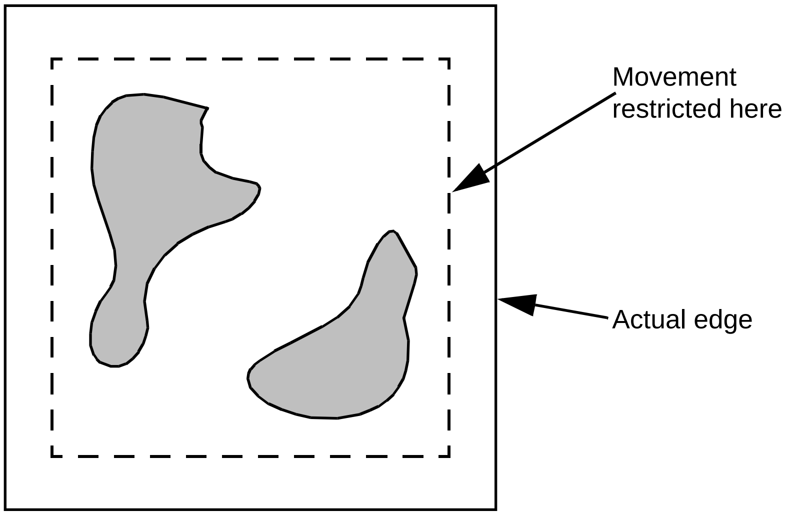

Figure 6-2 The buffer zone surrounding each environment.

scales, it is possible to determine the orientation of the texture to use it for navigation purposes. Consequently, this navigation technique was rarely successful (See Chapter 8).

The targets were manually placed in the worlds. The home target was an oil tanker platform (See Appendix A) while all other targets were different ships. Their orientation was randomly selected. All ships were used at full scale except for one which was scaled up so as to be approximately equivalent in size to the others. The targets were numbered in order to be easily identified by the subjects. A white cube with the target’s identification number on all sides was placed above the target.

The radial grid used in the grid treatment is shown in Figure 6-3. It is primarily constructed from a center post (red) which does not show a direction, and four colored posts in each cardinal direction. The outer posts each have a “flag” which points inward toward the red inner post. The outer posts are placed in a clockwise ordering of green, yellow, brown, and blue. All the posts are 2500 meters high. There are three concentric rings marking the range. The red inner ring is placed at 10000 meters radius from the center, the yellow middle ring at 20000 meters radius, and the white outer ring at 40000 meters radius. The outer posts are placed on the white outer ring. Black radial lines are present every 45 degrees and extend beyond the white outer ring.

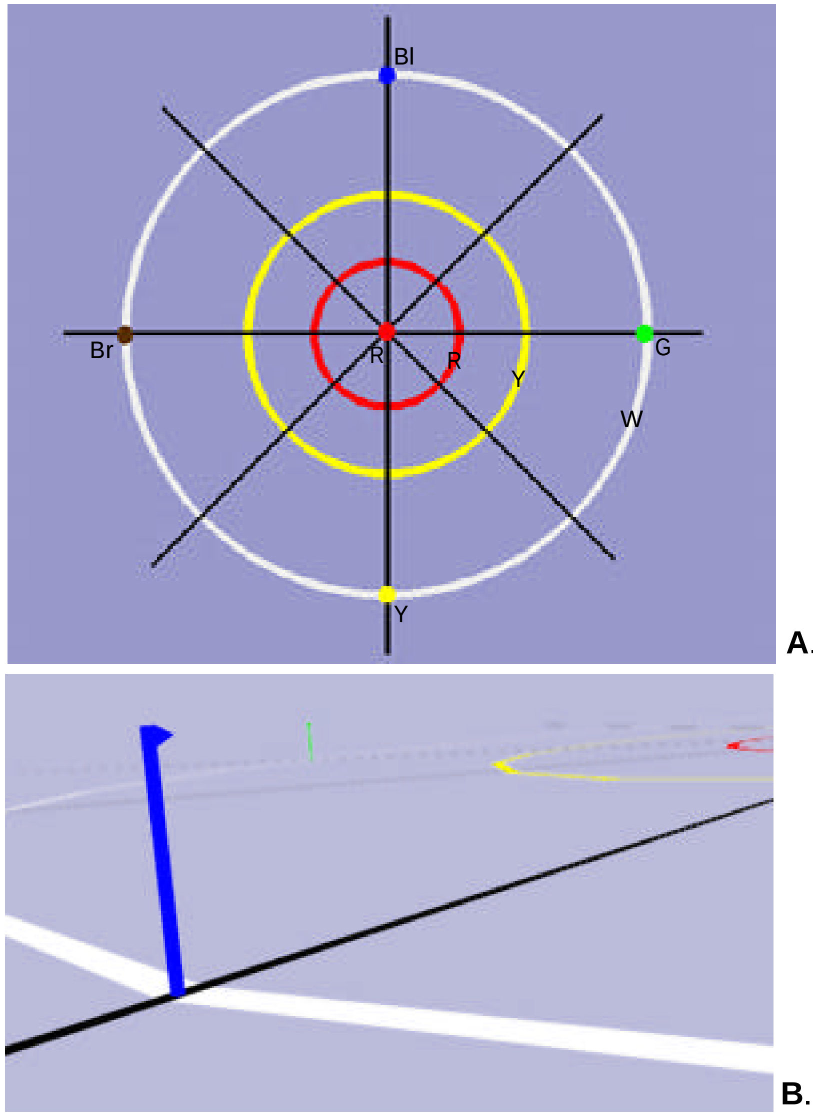

Figure 6-3 A. The radial grid as seen from above. B. The outer posts.

The map used in the map treatment was actually the same geometric data used for the environment. The map is shown in Figure 6-4. The blue sea texture was replaced by a grey background for contrast with the actual environment. The land masses were colored as described earlier. A red sphere (the “you-are-here” marker) was used to identify the view-point position. Rather than draw the map in an upright position, the map is presented flat and in the same orientation as the environment itself. The map was placed relative to the viewpoint during movement. This was done subjectively requiring only that the map be entirely visible at all times but that it be as small and unobtrusive as possible. The intent was for subjects to feel that the map was in front of their chest.

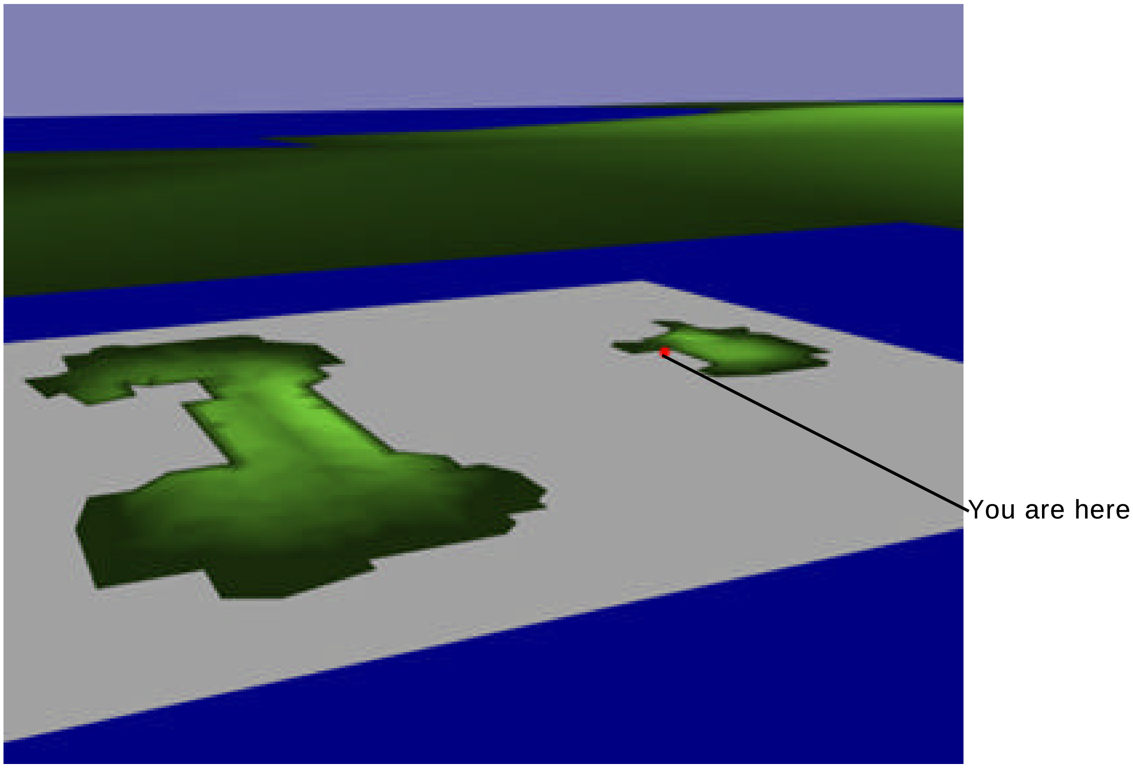

Figure 6-4 The map used with the map treatment. This environment was not one of the five used in the experiment.

The map/grid treatment was implemented by simply placing the grid over the map and also in the environment itself as in the grid treatment. The map/grid treatment is shown in Figure 6-5. Notice the numbered cube identifying the home target as target zero. So as to be able to use any treatment with any environment, maps were constructed for all worlds. Then, the grid could be overlaid on any map or environment.

The computing hardware and graphics engine used was a Silicon Graphics Onyx™ Reality Engine 2™ workstation. The only peripheral device used was a Fakespace Inc. BOOM3C™ display and tracker. The BOOM3C is a full color, high resolution (1280x1024 pixels) stereoscopic† CRT-based display mounted on a counter-balanced mechanical arm (See Figure 6-6 A). The display is held to the eyes with one hand. There is

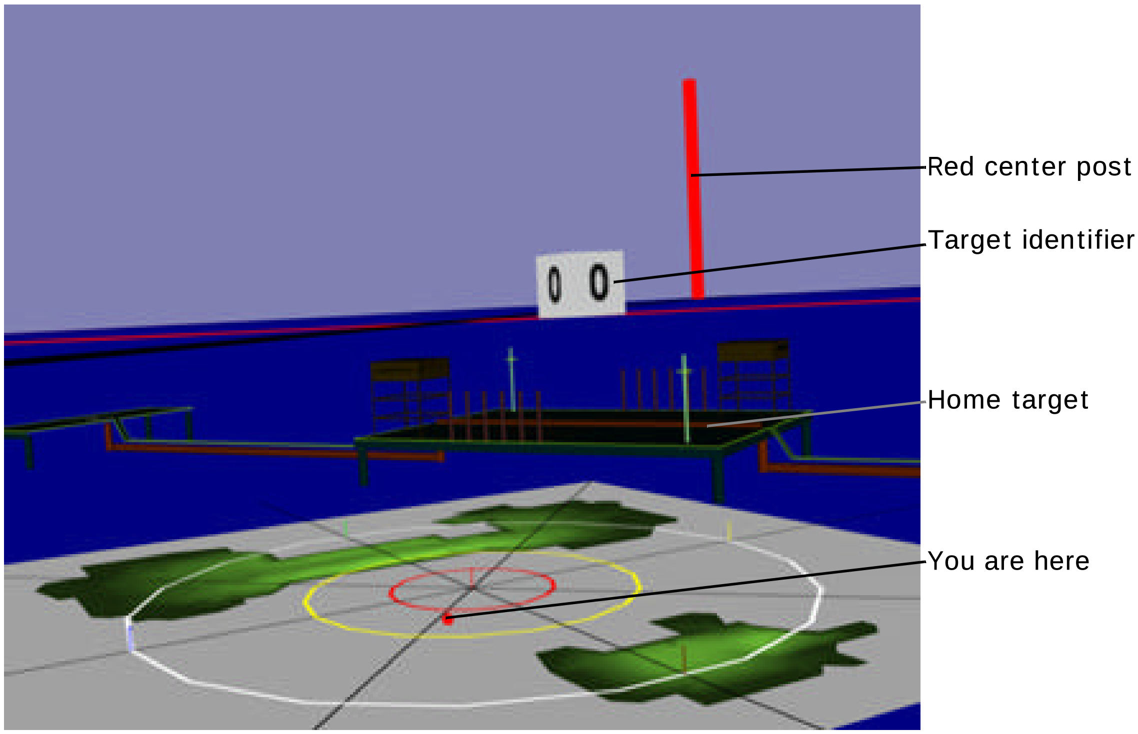

Figure 6-5 The map/grid treatment.

no external light seepage. The hand control has a single button and an eight position thumb-operated joystick (See Figure 6-6 B). Only the up and down positions of the joystick are used. The position and orientation of the head are tracked through the mechanical arm.

Motion is controlled via an acceleration metaphor by which the subject accelerates forward in the virtual world by pushing up on the joystick and backward by pulling down. Velocity is bounded by a speed limit approximately equal to Mach 3 (993 m/s or 2223 mph) Movement is *always* in the direction of view. The subject may stop at any time by pushing the red thumb button. Orientation cannot be altered with the buttons or joystick. The BOOM3C was also equipped with a microphone attached to the video camera. The audible cue used to identify the extents of the world was produced from a Silicon Graphics Indigo2™ Extreme™ workstation in the laboratory.

† The imagery used in this experiment was monoscopic.

A.

B.

Figure 6-6 A. The Fakespace Inc. BOOM3C™. B. The BOOM3C hand controller with single button and thumb-operated joystick (Different from that shown in A.)

Procedure

As first suggested by Thorndyke and Goldin (1983), the effect of natural human spatial abilities on wayfinding is a relevant issue to this research. Because this experiment will look at wayfinding in a very different (non-physically based) form, Thorndyke's assertion that a relationship exists between certain cognitive factors and wayfinding performance requires further investigation.

The experiment measured subjects' abilities in spatial orientation, spatial scanning, visualization, and field dependence. The tests were selected from both the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Dermen, 1976) available from the Educational Testing Service, and the Embedded Figures Test (Witkin, Oltman, Raskin & Karp, 1971). These cognitive factors are defined as:

- **Spatial orientation:** the ability to perceive spatial patterns or to maintain orientation with respect to objects in space
- **Spatial scanning:** speed in exploring visually a wide or complicated spatial field
- **Visualization**: the ability to manipulate or transform the image of spatial patterns into other arrangements
- **Field Dependence:** the ability to hold a given visual percept of configuration in mind so as to disembed it from other well defined perceptual material

Each of these tests as well as examples and instructions are included in Appendix A. All subjects were first given each of these tests before going on to the wayfinding portion of the experiment.

Subjects were tested for color blindness.[†] This was necessary due to the importance of color discrimination for the grid treatments. All subjects were tested on all treatments. Before beginning, the instructions were read aloud and the subject was given an opportunity to ask questions. The order of treatment presentation and the environments to be used with each had been predetermined at random. However, all subjects were given the control treatment on a separate environment as a practice trial. This was done to introduce the apparatus and the task in such a way as to limit the effect on the consequential data.

The general wayfinding task performed for all treatments required the subject to perform five naive searches followed by one primed search. The subject starts on (actually

† There were no cases of color blindness.

above) the home target and proceeds to search the environment for each of the five ships which have been numbered and shown to the subject in the instructions. No a priori information is given as to their whereabouts. These search times are recorded. Once the last target has been located, the subject is required to return to the home target. This search time was also recorded as well as the overall amount of time spent in the environment.

Subjects were given as much time as needed to complete the task. However, the trial could be discontinued at the subject's request. This was allowed only in cases when either the subject felt unable to make any progress toward task completion after an extended period of time (always at least 15 minutes) or the subject became unable to continue for physical reasons.[†]

During task execution, the subject's position and orientation (direction of view) was sampled approximately once per second. This data proved to be invaluable to the success of the experiment as it allowed reconstruction and measurement of several factors such as distance travelled, average velocity, and search coverage. These will be described in detail in Chapter 7.

All trials were audio and videotaped. During the trials, subjects were asked to "think aloud" as a method of knowledge extraction specifically aimed at understanding search strategies. Subjects were often prompted to describe their purpose in performing certain actions, their feelings as to the potential for success, and other general descriptive information. At no time were subjects assisted in the performance of the wayfinding task.

Following each trial, subjects were required to draw a map sketch of the environment in as much detail as possible. A technique similar to Lynch (1960) was used. Subjects were free to sketch the environment at will starting from a blank piece of paper. This method allows the subject some artistic freedom to sketch what was seen as "important" as it was viewed.

† There were two cases of motion sickness.

The causal relationship in this experiment involves three major factors: the principles, the tasks, and the worlds (spatial characteristics). As described in the previous chapter, there can be many different types of virtual worlds exhibiting various spatial characteristics. Clearly, it is not feasible to address this problem in such a way as to investigate the effects of wayfinding principles on all types of worlds. Consequently, this experiment has been constrained by the spatial characteristics of the worlds used. They are relatively simple and are physically similar. This is a natural starting point for research of this nature in that the spatial characteristics of the world are easily understood. This allows subjects to focus on the experimental task itself rather than on understanding the unusual attributes of the space. The objective is to exploit the conceptual model and cognitive skills of the user for navigation in virtual space without making it a barrier. Differences between physical reality and virtual reality should be clear and intuitive.